Study of the blue hydrogen production process involving a conversion of the co-produced carbon dioxide into methane

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ABSTRACT

Blue hydrogen is a promising low-carbon energy source, produced efficiently through Autothermal Reforming (ATR) while capturing over 91% of CO_2 emissions. This study enhances sustainability by converting captured CO_2 into methane, reducing waste and maximizing resource utilization. With its economic feasibility and alignment with Saudi Vision 2030, blue hydrogen serves as a key transitional fuel, leveraging existing natural gas infrastructure while paving the way for a cleaner energy future.

OBJECTIVE

- **Efficient Blue Hydrogen Production** using ATR with CCUS to minimize CO_2 emissions.
- **Sustainable Hydrogen Process** by converting CO_2 into synthetic methane via the Sabatier reaction.
- **Cost Optimization** through CO_2 recycling and reduced raw material consumption.
- **Supporting Saudi Vision 2030** by promoting low-carbon hydrogen solutions.
- **Future Expansion Potential** to meet rising demand in petrochemical and energy sectors.

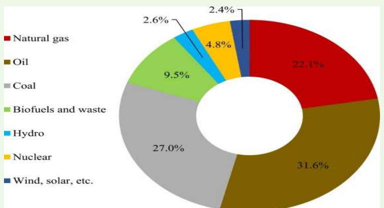


Figure 1 Distribution of global supply of primary energy by fuel type in 2020

Equipment Design

The system utilizes the ATR reactor (R-100) at 30 bar and 950°C to convert methane, steam, and oxygen into hydrogen-rich syngas, with a nickel-based catalyst inside the Plug Flow Reactor (PFR) ensuring maximum efficiency. An internal heat management system minimizes external energy demands. The heat exchanger (E-101), a counterflow shell-and-tube system with a 169.9 m² heat transfer area, optimizes heat recovery and reduces thermal losses. The flash drum (V-101) separates 99% pure methane from water and CO_2 through pressure and temperature variations. This integrated design enables sustainable blue hydrogen production, efficient CO_2 utilization, and enhanced economic feasibility.

Table 2 Heat Exchanger (E-101)

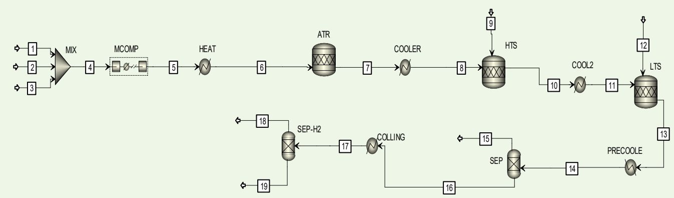
E-101			
Q (kW)	7571	Number of tubes	270
Shell pass	1	Tube arrangement	Square
Tube pass	2	Tube pitch (m)	0.0625
Heat transfer Area (m²)	169.9	Bundle dimeter (m)	1.295
Tube dimension		Shell dimeter (m)	1.373
d_o (mm)	50	Baffle spacing (m)	0.55
		Baffle cut	25%
d_i (mm)	46	Length (m)	1.488
u_t (m/s)	4.643	u_s (m/s)	22.07

Table 3 Autothermal Reactor (R-100)

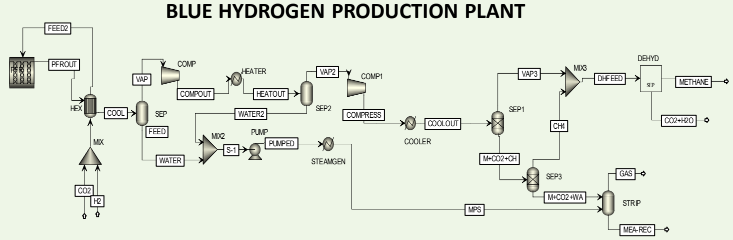
Reaction		Data for Reactor		Data for Tube	
Symbols	Final output	Symbols	Final output	Symbols	Final output
Kreforming (m³/mol*s)	$2.1675*10^{-5}$	V (m³)	20.784	V (m³)	0.1278
Koxidation (m³/mol*s)	$1.0318*10^{-5}$	Time (s)	310.790	N (number)	540
Rreformin (mol/m³*s)	0.369	D (m)	2.066	D (m)	0.0762
Roxidation (mol/m³*s)	0.0067	h (m)	7.198	L (m)	0.0519
$-r_{A(total)}$ (mol/m³*s)	0.375	A (m²)	46.725	A (m²)	6.7088
		Thickness (mm)	219	Thickness (mm)	9.05226

SIMULATION OF PROCESSES

The system relies on the ATR reactor, which converts methane, oxygen, and steam into syngas rich in hydrogen, supported by pre-heaters, heat exchangers, and a water-gas shift reactor to enhance yield and reduce emissions. The captured CO_2 is then utilized in the PFR methanation reactor, where it is converted into synthetic methane using a nickel-based catalyst, with compressors and separators ensuring product purity.



BLUE HYDROGEN PRODUCTION PLANT



METHANATION PRODUCTION PLANT

ECONOMIC STUDY

Table 4 Capital cost of Blue Hydrogen

Equipment Type	Equipment Code	Purchasing Cost in millions of dollars
Mixer	M-101	0.61
Multi Compressor	K-101	508.3
Heater	H-101	45.5
Cooler	C-101	0.880
	C-102	0.880
	C-103	0.880
	C-104	0.880
Reactor	R-101	15.2
	R-102	8.63
	R-103	5.71
Separator	V-101	3.76
Flush drum	V-102	3.46
Total capital cost		594.69

Table 5 Capital cost of Methanation

Equipment Type	Equipment Code	Purchasing Cost in millions of dollars
Mixer	M-201	0.47
	M-202	0.524
	M-203	0.578
Compressor	K-201	2.13
	K-202	2.4
Reactor	R-201	0.105
Heat Exchanger	E-201	0.139
Pump	P-201	0.0102
Cooler	C-201	0.88
Heater	H-201	0.73
	H-202	1.36
Vessel	V-201	0.26
	V-202	0.26
	V-203	6.41
	V-204	3.33
	V-205	0.562
Total capital cost		20.1482

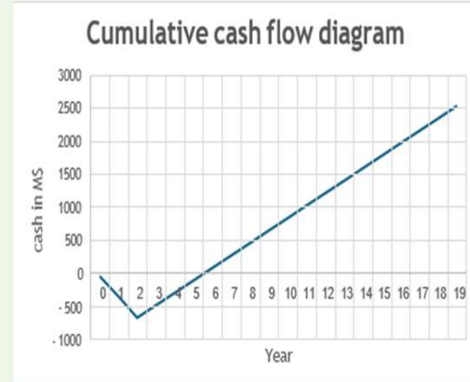


Figure 2 Cumulative cash flow diagram

CONCLUSION

Blue hydrogen production via ATR with CO_2 methanation achieved 99.99% hydrogen purity, capturing 91% of CO_2, and producing 819,831 tons of H_2 and 303,320 tons of CH_4 annually. Economic analysis estimates a cost of \$1.23–\$1.66 per kg and a payback period of 5 years, 9 months. This process enhances sustainability, supports Saudi Vision 2030, and strengthens the clean hydrogen economy.